



**UNIVERSITI PUTRA MALAYSIA**

**SKID RESISTANCE AND TEXTURE DEPTH ANALYSIS OF  
STONE MASTIC ASPHALT**

**ABDULLAHI ALI MOHAMED**

**FK 2001 66**

**SKID RESISTANCE AND TEXTURE DEPTH ANALYSIS OF  
STONE MASTIC ASPHALT**

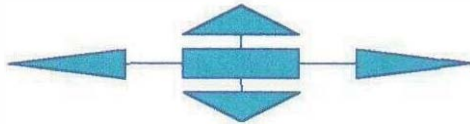
**By**

**ABDULLAHI ALI MOHAMED**

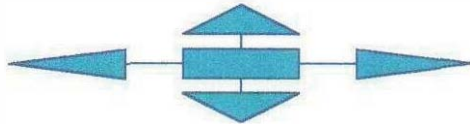
**Thesis Submitted in Fulfilment of the Requirements for the Degree of  
Master of Science in the Faculty of Engineering  
Universiti Putra Malaysia**

**January 2001**





*Dedicated to My Beloved Family:*  
*Dad (Ali Mohamed Hogsade), Mum (Haw*  
*Haji Hassan)*  
*Brothers (Dr. Cabdiryaq, Abuker,*  
*Cabdikadir) and Sisters (Fatima, Canab and*  
*Luul)*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in  
fulfilment of the requirement for the degree of Master Science

**SKID RESISTANCE AND TEXTURE DEPTH OF STONE MASTIC  
ASPHALT (SMA)**

**By**

**ABDULLAHI ALI MOHAMED**

**January 2001**

**Chairman: Mr. Ratnasamy Muniandy**

**Faculty: Engineering**

The skid resistance of highway pavements, particularly when wet, is a serious problem. As traffic speeds and densities continue to rise, the chances of skidding accidents as well as their consequences are both growing at an alarming rate with each passing year. Skid resistance between tire and road surface is a function of contact area. Maximum grip may be generated in dry conditions while in wet conditions the presence of surface water on the road surface may reduce the contact area and consequently reduce the available grip.

Since 1994, Universiti Putra Malaysia had been involved in Stone Mastic Asphalt (SMA) Technology research, to formulate for Malaysian roads, SMA, presents a very uniformly textured surface that can achieve grip or friction between rubber tire and road surface. In this study, pavement surface

interaction was given the highest priority, and slab specimens were prepared by varying gradation of SMA 14 to simulate the actual behavior of field skid resistance. Conventional hot mix asphalt was also prepared as a control.

The results of skid resistance and texture depth were tabulated with the variables (Angularity Number, Particle Index, and Percentage of Asphalt, Voids in Total Mix, Voids in Mineral Aggregate, Distribution of Coarse Aggregate and Polished Stone Value). Statistical analyses were performed to assess the relationship between physical and mechanical properties of the mix, and to study how the mixing materials contribute to the skid resistance and the texture depth of SMA. SPSS and EXCEL packages were employed to investigate these relationships.

The foregoing data indicate convincingly that Angularity Number as measured by the angularity test, had highly significant effects on the skid resistance of SMA. In this case, the British Portable Number is shown to increase with increasing value of angularity number. For coarse aggregate and percentage of asphalt has significant effect  $P < 0.05$  on texture depth.

It was also noted that the data of skid resistance and texture depth indicated a wide spread of values obtained ranging from SMA 14 ranging 93 up to 124 BPN units, regardless of composition of the mixture. It may therefore be concluded that SMA has the potential to optimize the contact area between tires and road surface under dry and wet surface conditions.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk ijazah Master Sains.

**RINTANGAN GELINCIRAN DAN KEDALAMAN PERMUKAAN  
CAMPURAN ASPHALT MAMAH**

Oleh

**ABDULLAHI ALI MOHAMED**

**Januari 2001**

**Pengerusi: Encik Ratnasamy Muniandy**

**Fakulti: Kejuruteraan**

Rintangan gelinciran permukaan turapan, terutamanya ketika basah, merupakan satu masalah yang serius. Ketumpatan dan kelajuan trafik meningkatkan peluang berlakunya kemalangan akibat gelinciran dan kesannya meningkat pada kadar yang membimbangkan. Rintangan gelinciran antara tayar dan permukaan jalan adalah merupakan satu fungsi permukaan sentuh. Permukaan sentuh maksimum boleh dicapai pada keadaan kering. Bila terdapatnya kehadiran lapisan air di dalam keadaan basah, ia mengurangkan lagi permukaan sentuh ini sekaligus mengurangkan geseran permukaan.

Semenjak 1994, unit penyelidikan keselamatan Jalan Raya UPM telah terlibat dalam kajian menghasilkan teknologi Campuran Asphalt Mamah bagi kegunaan jalan raya di Malaysia; di mana ia dapat memberikan permukaan

yang kasar yang boleh mengurangkan kesan gelinciran antara tayar kenderaan dan jalan.

Dalam kajian ini, interaksi permukaan jalan diberikan keutamaan dan specimen slab disediakan dengan menggunakan variasi gradiasi SMA14 bagi mendapat keadaan sebenar di jalan terhadap rintangan gelinciran. Campuran asphalt panas yang lazim digunakan di jalan di sini juga disediakan sebagai sampel kawalan.

Keputusan rintangan gelinciran dan kedalaman permukaan ditabulusikan dengan pembolehubah ( AN, PI, PA, VMA, DOC dan PSV). Analisa statistik juga dijalankan bagi membantu mendapatkan hubungan antara sifat mekanikal dan fizikal campuran berkenaan dan juga bagi mengkaji bagaimana campuran ini menyumbang kepada rintangan terhadap gelinciran dan kedalaman permukaan asphalt mamah. Analisa ini dilakukan dengan menggunakan SPSS, SAS dan EXCEL.

Daripada data yang dianalisis, didapati Nombor Angularasi yang diperolehi melalui ujian Nombor Angularasi menghasilkan kesan paling ketara terhadap rintangan gelinciran campuran asphalt mamah. Dalam kes ini didapati BPN meningkat apabila meningkatnya nombor angularasi. Sementara itu, batuan kasar dan peratusan asphalt mempunyai kesan yang ketara terhadap kedalaman permukaan.

Dalam kajian ini juga mendapati data rintangan gelinciran dan kedalaman permukaan bagi SMA 14 adalah dalam lingkungan 93 ke 124 unit BPN tanpa mengira komposisi campuran berkenaan. Dengan ini dapat disimpulkan bahawa SMA, mempunyai potensi bagi memaksimumkan kawasan sentuh antara jalan dan tayar dalam keadaan kering dan basah.



## **ACKNOWLEDGEMENTS**

I would like to express my sincere gratitude first and foremost to Almighty Allah for his guidance during my study. I would like to express my most sincere thanks and appreciation to my supervisor Mr. Ratnasamy Muniandy for his guidance, advice, and constructive criticism throughout the course of this study. I also wish to extend my gratitude to Mr. Hussain Hamid, and Associate. Prof. Ir. Megat Johari Megat Mohd Noor for their support, constructive criticism, and valuable comment in making this study a success.

I would like to thank the Ministry of Science, Technology, and the Environment, that has enabled me to complete the study without encountering any financial difficulties.

I am also indebted to the technical and administrative staff of Civil-Engineering Department especially Haji Razali Mohd Amin for his patience and assistance throughout my study at Road Safety Research Center (RSRC). Thanks to all lectures of civil engineering for their help in diverse ways.

Last but not least, I would like to express my deep gratitude and great indebtedness to my younger brother Abuker Ali for his emotional support and continual encouragement during my study. I pray that Almighty God may bless



all that have contributed in whatever way to the success of my studies at  
Universiti Putra Malaysia but have not mentioned here.

I certify that an Examination Committee met on 22<sup>th</sup> January 2001 to conduct the final examination of Abdullahi Ali Mohamed on his Master of Science thesis entitled "Skid Resistance and Texture Depth Analysis of Stone Mastic Asphalt " in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**BUJANG B.KIM HUAT, Ph.D.**

Department of Civil Engineering  
Faculty of Engineering,  
Universiti Putra Malaysia  
(Chairman)

**RATNASAMY MUNIANDY, M.Sc.**

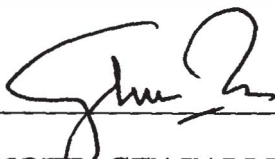
Department of Civil Engineering  
Faculty of Engineering,  
Universiti Putra Malaysia  
(Member)

**MEGAT JOHARI MEGAT MOHD NOOR, M.Sc**

Department of Civil Engineering,  
Faculty of Engineering,  
Universiti Putra Malaysia  
(Member)

**HUSSAIN HAMID M. Sc.**

Department of Civil Engineering ,  
Faculty of Engineering,  
Universiti Putra Malaysia  
(Member)

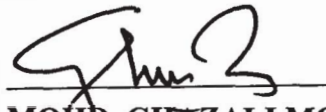


**MOHD. GHAZALI MOHAYIDIN, Ph.D**

Professor  
Deputy Dean of Graduate School  
Universiti Putra Malaysia

Date: 20 MAR 2001

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.



**MOHD. GHAZALI MOHAYIDIN, Ph.D.**  
Professor  
Deputy Dean of Graduate School  
Universiti Putra Malaysia

**Date: 12 APR 2001**

## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



---

Name: Abdullahi Ali Mohamed

Date: 20/3/2001

## TABLE OF CONTENTS

	Page
<b>DEDICATION</b> .....	ii
<b>ABSTRACT</b> .....	iii
<b>ABSTRAK</b> .....	v
<b>ACKNOWLEDGEMENTS</b> .....	viii
<b>APPROVAL SHEETS</b> .....	x
<b>DECLARATION FORM</b> .....	xii
<b>LIST OF TABLES</b> .....	xvi
<b>LIST OF FIGURES</b> .....	xviii
<b>LIST OF APPREVIATION</b> .....	xx
<b>CHAPTER</b>	
<b>I INTRODUCTION</b> .....	
Background of the study.....	1
Tire -Pavement Interaction Phenomena.....	5
Problem Statement .....	8
Brief History of Stone Mastic Asphalt .....	9
Project Aim and Objectives .....	12
Research Hypothesis .....	12
Research Significance .....	13
Scope of Study .....	14
<b>II LITERATURE REVIEW</b> .....	
Skidding and Skid resistance .....	15
Recommendations and Specifications of Skid Resistance ...	20
Belgium .....	20
Great Britain .....	21
France .....	22
Japan .....	24
Malaysia .....	25
Skidding and Skid Resistance in Malaysia .....	25
Methods of Skid Resistance Measurements .....	26
Road Measuring Instruments.....	26
Comparison and Correlation of Skid Testing Instruments...	30
Indirect Skid resistance Measurements .....	32
Micro-texture Measurements .....	32
Macro-texture Measurements .....	32



	Sand –patch Method .....	32
	Grease Method .....	33
	Profile and Filtered Ratio Method .....	34
	Out-flow Meter .....	34
	Review of Pavement Surface Functions .....	35
	Material Properties of Surface Mix Design .....	36
	Effects of Angularity Number on Skid Resistance .....	36
	Aggregate Size and Shape Influence on Skid Resistance ...	37
	Wear Resistance of Aggregate .....	39
	Skid Resistance of Bituminous Pavements .....	40
	Hot-Rolled Asphalt .....	41
	Surface Dressing .....	42
	Porous Asphalt .....	43
	Mechanics of Tire-Pavement Interaction .....	44
	Pavement Surface Texture and Skid Resistance .....	47
	Problems Associated with Texture .....	48
	Traffic Noise .....	48
	Spray .....	50
	Factors affecting Skid Resistance other than Surface.....	51
	Vehicle Tires' Influence on skidding .....	51
	Vehicle speed Influence on skidding .....	53
	Geometrics .....	53
	Surface Texture and Contact Characteristics .....	54
	Phenomena of dynamic hydroplaning .....	56
	Viscous Hydroplaning .....	62
	Rubber Reversion Hydroplaning .....	62
<b>III</b>	<b>METHODS AND MATERIALS .....</b>	<b>64</b>
	Overview of Study Design .....	64
	Methodology .....	68
	Material Selection .....	69
	Aggregate Impact Value .....	69
	Aggregate Crushing Value .....	70
	Los Angeles Abrasion Test .....	70
	Determination of Flakiness Index .....	71
	Polished Stone Value .....	71
	Angularity Number .....	73
	Binder Selection for SMA Use .....	73
	Penetration Test .....	73
	Asphalt Thickness .....	74
	Selection of Gradation .....	74
	Over View of Marshall Mix .....	76
	Preparation of Specimen for Marshall .....	76
	Marshall Stability and Flow of Bituminous Mixtures.....	80
	Optimum Asphalt Content .....	82
	Method of Skid Resistance Measurement....	83

	Fabrication of Design Mould.....	83
	Preparation of SMA Slabs .....	85
	Specimen Preparation .....	85
	Skid and Texture Depth Testing .....	86
	British Pendulum Tester .....	86
	Sand Patch Method .....	87
	Step-Wise Regression Method .....	89
	Forward Procedure .....	89
	Back Elimination .....	90
	Step-Wise Procedure .....	91
<b>IV</b>	<b>RESULTS AND DISCUSSION .....</b>	<b>92</b>
	Material Selection for SMA Use.....	92
	Gradation Selection of SMA 14 .....	101
	Determination of Asphalt Content .....	102
	Preliminary Evaluation and Analysis .....	103
	Relationship between Physical and Mechanical proper..	106
	Skid Resistance of Surface Mix .....	107
<b>V</b>	<b>CONCLUSION AND RECOMMENDATION.....</b>	<b>121</b>
	Summary of Material Properties.....	121
	Summary of Optimum Asphalt Content .....	122
	Conclusion of the Study .....	123
	Limitation of the Study .....	124
	Future Research .....	125
	<b>BIBLIOGRAPHY .....</b>	<b>126</b>
	<b>APPENDIX</b>	
	<b>A</b> Determination of Asphalt Content .....	134
	<b>B</b> Single Factor Analysis .....	144
	<b>C</b> Stepwise Output .....	146
	<b>VITA</b> .....	158



## LIST OF TABLES

Table	Page
1.1 Road crash by Road Surface Condition .....	3
1.2 Percentage of Skidding Accidents .....	4
2.1 Suggested Minimum Value of Skid Resistance.....	22
2.2 Recommended Polished Stone Value .....	23
2.3 Recommended Macro-texture .....	23
2.4 Effect of Macro texture on the change skid resistance with Speed .....	33
4.1 Polished Stone Value .....	94
4.2 Los Angles Abrasion Test .....	95
4.3 Aggregate Impact Value .....	95
4.4 Aggregate Crushing Value .....	96
4.5 Soundness Test .....	97
4.6 Flakiness Index Test .....	97
4.7 Angularity Number .....	99
4.8 Penetration of Asphalt .....	97
4.9 Softening Point of Asphalt .....	97
4.10 Results of Thick Film Thickness .....	100
4.11 SMA 14 five Gradations .....	101
4.12 SMA14 Physical and Mechanical Properties.....	102
4.13 Statistical Relationship between Mixing materials	107
4.14 SMA 14 Skid Resistance and Texture Depth .....	108
4.15 ANOVA, Relationship Skid Resistance and Variab.	118
4.16 Density and Distribution Coarse Aggregate .....	118
4.17 Distribution of Fine and Coarse Aggregate .....	119
4.18 Density and and Distribution of Fine Aggregate ....	119

4.19	Variance of Density, Distribution of Aggregate .....	120
5.1	Aggregate Physical Properties .....	121
5.2	Asphalt Properties.....	122

## LIST OF FIGURES

Figure	Page
1.1 Road Development Indicators .....	2
1.2 Relationship between Skid and Accidents.....	5
1.3 Road Allocation and Expenditures .....	8
1.4 Stone Mastic asphalt and Hot Mix Asphalt .....	10
2.1 Vechile Skidding Phenomena .....	16
2.2 Presence of Surface Water on Road Surface .....	17
2.3 Dirty Pavements or Contaminated pavement .....	17
2.4 The Effect of Cumulative Passes on Skid.....	19
2.5 Sideway Force Co-efficient Routine I. Machine ....	27
2.6 Trailer for Measurement BFC .....	28
2.7 British Pendlum Tester .....	29
2.8 Comparison of Data Between DF tester and BPT	31
2.9 Smooth and Angular Aggregate.....	37
2.10 Size Distribution of Coarse Aggregate .....	38
2.11 Porous Asphalt Surface .....	44
2.12 Components of Friction .....	46
2.13 Wet Footprint and the Contact Length .....	63
3.1 Flow Chart of The Study.....	67
3.2 Gradation Selection Chart .....	75
3.3 Upper and Lower Testing Head .....	82
3.4 Dimensions Slab Specimen .....	84
3.5 A slab for Skid and Texture Testing .....	86
3.6 Sand Patch .....	87
4.1 Surafce Area of SMA14 .....	103
4.2 Relationship Between Surafce Area and Asphalt.....	104
4.3 Relationship Between VTM and Density.....	105
4.4 Density of SMA 14 Gradations .....	106



4.5	Comparison of Texture Depth and ACW.....	109
4.6	Comparison of Skid Resistance of SMA & ACW....	110
4.7	Effect of Density on Texture Depth .....	113
4.8	Effect of Texture depth on Skid Resistance.....	114
4.9	Effect of Film Thickness on Skid Resistance .....	115
4.10	Effect of Aggregate Size on Skid Resistance .....	116

## **LIST OF ABBREVIATIONS**

<b>A.C.V</b>	<b>Aggregate Crushing Value Test.</b>
<b>A.I.V</b>	<b>Aggregate Impact Value Test.</b>
<b>AASHTO</b>	<b>American Association of State Highway and Transportation Official</b>
<b>AAV</b>	<b>Aggregate Abrasion Value</b>
<b>AN</b>	<b>Aggregate Angularity Number</b>
<b>ANOVA</b>	<b>Analysis of Variance</b>
<b>ASTM</b>	<b>American Society for Testing and Materials</b>
<b>DOC</b>	<b>Distribution of Coarse Aggregate</b>
<b>DOF.</b>	<b>Distribution of Fine Aggregate</b>
<b>HFWC</b>	<b>High Friction Wearing Coarse</b>
<b>HMA</b>	<b>Hot Mix Asphalt</b>
<b>BPN</b>	<b>British Portable Number</b>
<b>PA</b>	<b>Percentage of Asphalt</b>
<b>JKR</b>	<b>Jabatan Kerja Raya</b>
<b>L.A</b>	<b>Los Angels Abrasion Test</b>
<b>LVDT</b>	<b>Linear Variable Differential Transformer</b>
<b>TTI</b>	<b>Texas Transportation Institute</b>
<b>MATTA</b>	<b>The Material Testing Apparatus</b>
<b>N. R.</b>	<b>Negri Roadstone Quarry</b>

<b>NAA</b>	<b>National Aggregate Association</b>
<b>OECD</b>	<b>Organisation for Economic Co-Operation and Development</b>
<b>OBC</b>	<b>Optimum Binder Content</b>
<b>PDRM</b>	<b>Royal Malaysian Police</b>
<b>PI</b>	<b>Particle Shape Index of stones</b>
<b>PSV</b>	<b>Polished Stone Value</b>
<b>PWD</b>	<b>Public Works Department</b>
<b>RSRC</b>	<b>Road Safety Research Centre</b>
<b>S. G.</b>	<b>Aggregate Specific Gravity Test</b>
<b>SAS</b>	<b>Statistical Analysis Software</b>
<b>SGC</b>	<b>Superpave Gyratory Compactor</b>
<b>SMA</b>	<b>Stone Mastic Asphalt</b>
<b>SPSS</b>	<b>Statistical Package for Social Science</b>
<b>SST</b>	<b>Super Shear Tester</b>
<b>TD</b>	<b>Texture Depth</b>
<b>TRRL</b>	<b>Transport and Road Research Laboratory</b>
<b>TSR</b>	<b>Tensile Strength Ratio</b>
<b>U.S.A</b>	<b>United States of America</b>
<b>UPM</b>	<b>Universiti Putra Malaysia</b>
<b>SMA-UPM</b>	<b>UPM – In House Procedure</b>
<b>VFA</b>	<b>Voids Filled with Asphalt</b>
<b>VMA</b>	<b>Voids in Mineral Aggregate</b>
<b>VTM</b>	<b>Voids in Total Mix</b>

## **CHAPTER I**

### **INTRODUCTION**

#### **Background of the Study**

Road surface requirement has been changing significantly over the last thirty years. In the fifties, surface evenness maintenance work was confined to remedying potholes. Assessment of wet weather skid resistance was at an early stage. Since then, in response to rapid growth, most countries have been concerned with road traffic safety (OECD, 1984).

Malaysia is one of the countries that experienced a rapid economic development for the last ten years. This economic growth accompanied by increased building of highways has resulted in a substantial increase of traffic-related problems, such as loss of human lives and properties.

Road Development Index (RDI) as shown in Figure 1.1, prepared by the Public Works Department Malaysia, reported that the RDI which measures the level of road development, taking into account both area and population size of the country, also improved significantly from 0.54 in 1985 to 0.80 in 1985 or an increase of 48% (PWD, 1999).

The road service level comprises three indicators, which measure total road length to population, total vehicles and per RM 100 million Gross Domestic Product (GDP), respectively. The road service level in terms of road length to population increased by 31% from 2.46 kilometres in 1985 to 3.22 kilometres of roads per 1000 persons in 1995.

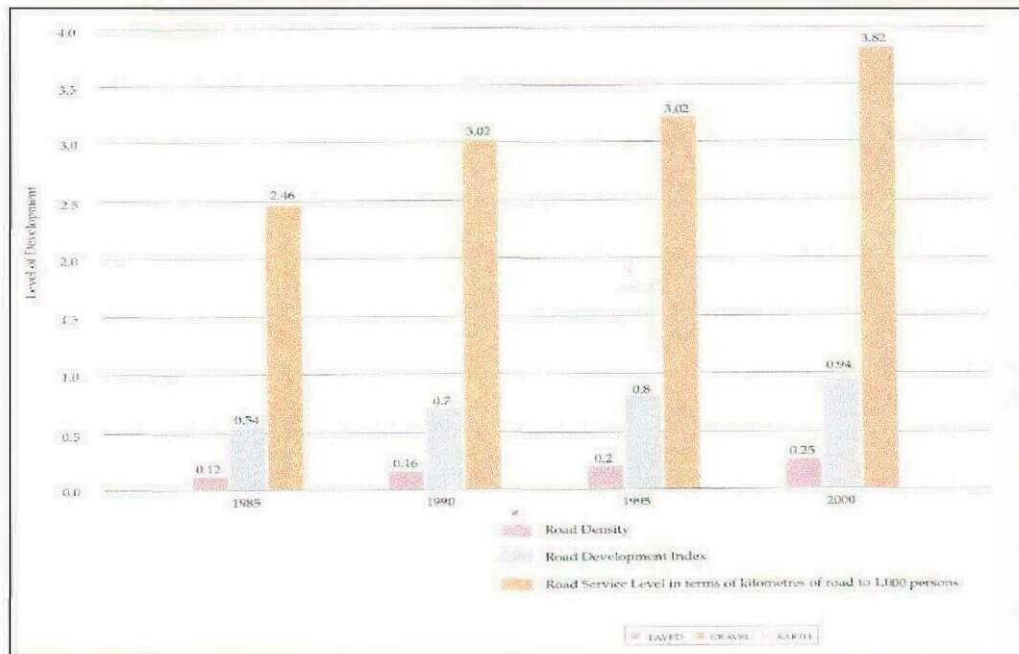


Figure 1.1 Road Development Indicators 1985-2000.  
(Source: Public Works Department, 1999)

As a result of this tremendous economic increase, Malaysia entered a different phase of motorization transition. It was observed that there was a resultant growth in the number of registered vehicles during the last two decades, for the period of 1977 to 1997. A total number of registered vehicles increased from 1.78 million vehicles in 1977 to 8.5 million vehicles in 1997 respectively, with the average rate of 7.9 %per annum (PWD, 1999).



This explosive growth of automobile use has brought in, the need to recognize road safety as a complex problem that must be addressed properly, in order to save lives and properties. In 1997 alone, a total of 56, 574 casualties were reported of which 6302 were death, 14,105 were hospitalized, 36,167 were slightly injured (PDRM, 1998). Accidents related to skidding constitute 15% of the total accidents registered.

The Statistical Report on Road Accidents in 1998 by Polis Diraja Malaysia shows that there is a total of 1328 road accidents by surface conditions such as flood, wet, oily and sandy, which accounted to 561 cases of fatal accidents and 767 cases of serious accidents.

**Table 1.1: Road Crash by Road Surface Condition**

Surface Condition	Types of Road Crashes		
	Fatal	Serious	Total
Dry	4,415	9,087	13,502
Flood	11	31	42
Wet	492	673	1,165
Oily	6	10	16
Sandy	52	53	105
Under Repair	16	41	60
<b>Total</b>	<b>4,995</b>	<b>9,895</b>	<b>16,654</b>

(Source: Polis Diraja Royal Malaysia, 1998)

Accidents related to skidding constituted 15% of the total accidents registered but deaths due to skidding comprises 25%. Studies by (Radin, 1993) have shown that the odd ratio of skidding is 4.7 times higher compared with dry surfaces. This is illustrated in Table 1.2 below: -